FINAL EVALUATION OF CONSTRUCTION AND PAVEMENT PERFORMANCE FOR STATE STUDY NO. 130 HOT IN-PLACE ASPHALT RECYCLING DEMONSTRATION PROJECT

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BACKGROUND

A hot in-place recycling (HIR) project using the MARTEC® process was constructed on Interstate 55 in Pike County during the period of December 1997 to July 1998. This was the first use of this equipment in the United States. The project covered both north bound and south bound roadways and was approximately 15 miles in length. Both inside and outside lanes were recycled. This equipment differed from earlier HIR equipment primarily in the method of heating the hot mix asphalt (HMA). Air heated to 1100° F was produced in a diesel fired furnace and blown onto the pavement through a manifold. The final mixing was by an elevated pug mill after which the recycled mixture dropped into the hopper of an HMA paver.

The principal objectives of this project were to evaluate this equipment to satisfactorily recycle to a depth of 2 inches and to evaluate the use of Superpave technology for design of the HIR mixture and quality control during construction.

PREVIOUS EVALUATION

This work is described by Alfred B. Crawley, Research Engineer at that time, in a Transportation Research Board paper entitled "Innovative Hot In-Place Recycling of Hot Mix Asphalt Pavement in Mississippi" and dated July 1998. The major conclusions denoted in the paper are summarized as follows:

- This paper describes the first use of the MARTEC® HIR equipment in the United States. While construction problems were encountered, it has been shown this equipment can adequately heat an existing HMA pavement to permit hot in-place recycling to a depth of 2 inches. Subsequent projects need to insure there is one entity in control of the entire operation. Both acceptable density and ride quality are attainable.

- This project demonstrated a method of designing the HIR mixture and monitoring construction with Superpave technology. Preliminary Dynamic Shear Rheometer (DSR) testing was used to select a rejuvenator and establish a beginning point for laboratory design. The recycled mixture design was done using the same superpave compaction parameters MDOT uses for virgin HMA mixture. Quality control testing with a Superpave Gyratory Compactor at the field laboratory was used to make adjustments in the rejuvenator rate and binder content in the virgin HMA. Preliminary DSR data for recovered binder from the recycled mixture indicate acceptable properties. Since there is as yet no Superpave strength test, the Asphalt Pavement Analyzer was used to compare the HIR mixture with a virgin HMA mixture containing different binder grades and the results indicated satisfactory resistance to rutting.

In a memorandum dated April 2, 1999, Mr. Crawley summarizes the results of a distress survey he personally made to the project. The following information is taken from this memorandum:

"There are some obvious deficiencies in the construction, with the most prevalent one being a rather distinct gearbox shadow and crack in the middle of each lane for a significant part of the project. There is a segregation problem that will affect performance but it does not appear to me to pose an immediate problem. There are areas where some raveling is occurring and areas where excessive heating was done that has caused premature oxidation cracking (blocking cracking). Additionally, there are some isolated areas of roughness. None of these problems, in my opinion, necessitates any major corrective action in the near term. There are many miles of high volume highways in Mississippi that need rehabilitation (primarily from rutting) much more than this one."

"Since this is a research project that was used to validate the use of Superpave procedures for selection of the rejuvenator, mix design and quality control, it would be beneficial to track its performance for at least 3 or 4 years. This would allow a good evaluation of the use of Superpave criteria for this type of pavement rehabilitation. Specifically, the performance parameters to be monitored are rutting and cracking, since these types distresses will indicate whether the mixture is either too plastic or too brittle."

FINAL CONSTRUCTION EVALUATION

Based on information gained during the HIR construction, the following conclusions can be drawn for this work:

- This HIR project was constructed on asphalt pavement that had received a previous hot in-place recycling application approximately 1-inch thick just 7 years prior to this one. It is believed that part of the construction problem with the MARTEC® process was that the upper layer of asphalt pavement had been heated before with propane gas causing the pavement surface to become brittle and to require higher temperatures to return into a liquid state. The hardness of the pavement surface required additional temperature and slowed the paving train down resulting in a loss of production.

- There were many mechanical and electrical problems with the HIR construction equipment. Possibly, this was caused by the machines being in a weather environment different from that in Canada and Europe. In one instance, the radiators on the equipment had to be removed and increased in size in order to operate under the heat.

- This work was conducted with one company performing the HIR recycling and a separate company providing the extra asphalt and paving and rolling of the hot mix. This operation could have gone smoother with possibly a better finished product if the total operation had been performed by one contractor.

FINAL PAVEMENT PERFORMANCE

Most recently, distress surveys were conducted by the Research Division and by District 7 in McComb. Findings from these surveys are described as follows:

- Cores were taken at various locations on the pavement roadway and showed stripping in the seal layer (between the recycled layer and in-situ layer).

- One major distress was oxidation in which the asphalt has been leached from the pavement.

- Other major distresses included extreme cracking both transversely and longitudinally.

- Rutting was found to be present to a small degree in various areas of the roadway.

RECOMMENDATIONS

Based on the condition of the recycled pavement, plans are to conduct a rehabilitation of the total roadway pavement that had been recycled during 1998. Also, if this recycling technique or any other is being used, a thorough investigation should be made into the history of the pavement to be recycled as well as to the machinery that will be used.

INNOVATIVE HOT IN-PLACE RECYCLING OF HOT MIX ASPHALT PAVEMENT IN MISSISSIPPI

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ABSTRACT

A hot in-place recycling (HIR) project utilizing the MARTEC process was constructed on Interstate 55 in Mississippi in the period from December 1997 to July 1998 in the first use of this equipment in the United States. Project size was 180,600 m^2 (216,000 yd^2). This equipment differs from earlier HIR equipment principally in the method of heating the hot mix asphalt (HMA). Air heated to 600°C (1100°F) is produced in a diesel fired furnace and blown onto the pavement through a manifold. An elevated pugmill does the final mixing after which the recycled mixture drops into the hopper of a HMA paver.

Principal objectives of this project were to evaluate this equipment to satisfactorily recycle to a depth of 50 mm (2 inches) and to evaluate the use of Superpave technology for design of the HIR mixture and quality control during construction. Preliminary testing with a dynamic shear rheometer (DSR) was used to select a rejuvenator and an initial point for mixture design. Quality control testing with a Superpave gyratory compactor (SGC) at the field laboratory was used to make adjustments in the recycled mixture. Limited DSR data from recovered binder indicates acceptable properties. The Asphalt Pavement Analyzer (APA) was used to compare the HIR mixture with HMA using differing binder grades.

While construction problems were encountered, it has been shown this equipment can adequately heat an existing HMA pavement to permit hot in-place recycling to a depth of 50 mm (2 inches). Both acceptable density and ride quality are attainable.

INTRODUCTION

Recycling pavements in situ is a topic that has long captured the interest of highway design and construction practitioners. There exists a vast deposit of valuable aggregates and binders in the road network. If feasible methods can be deployed to rehabilitate old pavements in situ with minimal additions of virgin materials, significant savings could be realized in terms of dollars, reduced inconvenience to the traveling public, and energy.

During the past twenty years, hot in-place recycling (HIR) of hot mix asphalt (HMA) has made great strides in overcoming some of the earlier shortcomings and has grown in importance as a rehabilitation alternative (Reference 1). For flexible pavements that are structurally adequate but have surface distress such as cracking or rutting, HIR can potentially be a viable alternative. This process reduces hauling and mining costs and results in the least disruption to the environment and the roadway. The potential exists to reduce the cost of milling and overlay projects by 15% to 25% through the use of HIR.

This paper describes an interstate highway rehabilitation project that used an innovative forced hot air system for heating and softening HMA pavement to facilitate HIR. Information on mix design of the recycled mixture, construction and limited field laboratory data are included in this paper.

DESCRIPTION OF TECHNOLOGY

The Mississippi Department of Transportation (MDOT) has constructed projects with three different generations of HIR equipment since 1978 (equipment manufacturers Cutler, Jackson, and Wirtgen), all using either open-flame or infrared heaters, and all using propane fuel for heating. These machines were able to recycle to a depth of only approximately 25 mm (1 inch). The project described herein was the initial use of Martec Recycling Corporation's forced hot air heating system in the United States. This equipment had been used previously in Canada and Europe.

The Martec recycling train includes these 4 components:

- two identical preheating units that heat and soften the HMA pavement,
- a heating and milling unit that heats, mills, adds rejuvenator and windrows the HMA,
- a heating and mixing unit that adds virgin mix, heats and stirs the combined mixture and then mixes the combined materials in an elevated pugmill mixer.

The recycled mixture is discharged directly from the pugmill mixer into the hopper of a conventional HMA paver with laydown and compaction following standard HMA paving procedures.

The four main unit equipment train extends approximately 65 m (213 feet) in length. Innovative features of the MARTEC include the hot-air/infrared heating system and the heat and stir process. The system heats air to approximately 600°C (1100 °F) in a diesel-fueled combustion chamber and blows this hot air directly onto the pavement through a manifold. Afterwards, the spent hot air is vacuumed back into the system. The heat and stir process refers to the final heating process where the windrow of existing pavement, virgin HMA mixture and rejuvenator is stirred by paddles to assist in drying moisture that may be present in the mix.

MISSISSIPPI PROJECT PARAMETERS

The MDOT began planning a HIR project after seeing the MARTEC equipment operating in Canada in October 1997. The primary objectives for the project are:

- evaluate the capability of MARTEC HIR equipment to recycle the existing HMA pavement to a depth of 50 mm (2 inches);

- determine if the recycled mixture design lent itself to Superpave design procedures from both the binder aspect and the mixture compaction and volumetrics aspect;
- evaluate the use of the Superpave compaction criteria for monitoring recycled mixture parameters during construction;
- determine the impact of the recycling process on recovered binder properties to include testing with bending beam rheometer (BBR), Brookfield viscometer, and dynamic shear rheometer (DSR) for specimens collected before heating, after heating but before addition of the rejuvenator, and the final product containing rejuvenator and virgin HMA mixture. This testing is time consuming and the results are not yet available for this aspect of the work.

This project was designed to recycle to a depth of 50 mm (2 inches) and produce a recycled mixture containing 80% reclaimed asphalt pavement (RAP) and 20% virgin HMA. The recycled mixture design was accomplished in cooperation with the Federal Highway Administration's (FHWA) Mobile Asphalt Laboratory and the local HMA contractor.

The project site is on the northbound and southbound lanes of Interstate 55 in Pike County, beginning at the Mississippi/Louisiana state line and extending northward for approximately 12.37 km (7.69 miles) for a total area of 49.5 lane kilometers (30.76 lane miles) or 180,600 m^2 (216,000 yd^2). This same location was hot in-place recycled in 1991-1992 using the Wirtgen HIR equipment and thus presented the interesting opportunity to perform a second recycling operation on a site. The original pavement structure on this site was completed in 1967 and consisted of 140 mm (5.5 inches) of dense graded HMA over 200 mm (8 inches) of cement treated base. A rehabilitation project in 1984 consisted of a surface treatment as a stress absorbing membrane interlayer and 65 mm (2.5 inches) of HMA. The HIR project in 1991-1992 recycled a nominal depth of 25 mm (1 inch) and added virgin HMA at a nominal rate of 27.1 kg/m^2 (50 $pounds/yd^2$). The primary distress on the site is block cracking with minimal rutting.

PRELIMINARY ENGINEERING AND MIX DESIGN

Preliminary engineering for this project consisted of structural evaluation by deflection testing, ride quality and rut depth with a laser South Dakota Profiler, and recycled mixture design. For pavement rehabilitation projects, MDOT backcalculates layer moduli and computes remaining life and needed overlay thickness. The analysis for this location indicated sufficient structural capacity was in place. The average IRI was 1.75 m/km (110 inches/mile) for the outside lanes and 1.50 m/km (95 inches/mile) for the inside lanes. Rut depth averaged 6 mm (0.24 inch) for the outside lanes and 5 mm (0.20 inch) for the inside lanes. The recycled mixture design is described below.

A primary objective of this research was to determine if the recycled mixture design lent itself to Superpave design procedures, from both a binder aspect and mixture compaction and volumetrics aspect. A recycling depth of 50 mm (2 inches) was selected based on the existing pavement layers and the desire to recycle to the maximum depth attainable. MDOT policy on pavement rehabilitation is to increase the cross slope from the old standard of 1.5% to the current standard of 2%. The decision was made to keep the edge of the traffic lane at its existing elevation and make the cross slope correction by raising the elevation at the centerline. In this way only the travel lanes would be affected by the hot in-place recycling and no work would be required on the paved shoulders. Additional HMA mixture in the amount of 27.1 kg/m^2 (50 pounds/yd^2) would be needed for the cross slope correction. Together with the recycling depth of 50 mm (2 inches), this amount of virgin material resulted in an 80/20 blend of existing/virgin material in the recycled mixture.

Samples of the existing pavement were obtained by sawing blocks from the pavement. These blocks were approximately 300 mm (1 foot) cubes and the top 50 mm(2 inches) was sawn from the blocks for use in mixture design. Additional information on mixture design is given in the analysis section later in this paper.

CONSTRUCTION SPECIFICATIONS

Specifications for the HIR work were largely taken from the HIR project done on the same site 6 years earlier. The HIR work was designated experimental and a committee was named to oversee the work. This committee was composed of representatives of the district and central office divisions of Materials, Construction, Roadway Design and Research. Since this was a Federal aid project, the Division office of the Federal Highway Administration was also represented on this committee. The committee was given authority to approve necessary changes in the HIR work immediately without waiting on normal paperwork to work through the organization. This allowed for changes such as variations in mix design to take place very fast.

Binder grade for the virgin HMA was PG64-22.

Specifications required hot air heating, an elevated pugmill and a minimum temperature of 120°C (250°F) of the recycled mixture when placed in the hopper of the paving machine. Specifications required the heated pavement to be windrowed and the rejuvenator mixed with the windrow before the virgin HMA is added.

Specifications required a minimum ambient air and pavement surface temperature of 7°C (45°F) for work to commence.

A minimum density of 92.0 percent of the maximum specific gravity was specified.

The Contractor was required to provide a laboratory for daily testing of the virgin HMA and the recycled mixture. Daily testing was to include asphalt content and gradation for the virgin HMA, and maximum specific gravity and specific gravity at N_{design} for the recycled mixture. N_{design} was established as 109 revolutions in the SGC. SGC test results were to be used for the purpose of making adjustments as needed to the application rate of the rejuvenating agent and the binder content in the virgin HMA. All adjustments were subject to the approval of MDOT and had as the objective keeping the air void content in the recycled mixture between 3% and 4%.

Areas not meeting density and/or smoothness requirements were required to be reprocessed without the addition of rejuvenator or virgin HMA.

Pavement smoothness specifications required a maximum profile index of 268 mm/km (17 inches/mile) using a California-type profilograph with a 5 mm (0.2 inch) blanking band. In addition, no individual bumps and/or dips could exceed 10 mm (0.4 inch) when measured from a chord length of 7.5 m (25 feet) or less.

Pay items for the HIR work included recycling by the square yard, rejuvenating agent by the gallon and virgin HMA by the ton. The HIR work included placement of the recycled mixture with a conventional paver and compaction.

CONSTRUCTION

The HIR work was done under Federal aid project number 59-0055-01-070-10. A supplemental agreement was executed to add the HIR work to this project. Prior to the supplemental agreement, only non-roadway work was planned for this section of the project. Work began in mid December 1997 and 4.8 lane kilometers (3 lane miles) were completed before construction was stopped for the Christmas holiday. There were efforts made in early January 1998 to re-start construction but lower than usual ambient temperatures combined with higher than usual rainfall made it difficult to attain reasonable production rates. For these reasons, work was halted on the project until April. When the HIR subcontractor was ready to begin work in early April 1998, the HMA production plant supplying the virgin HMA was undergoing major repairs (replacing the dryer). By late April a decision was made to truck the virgin HMA aggregate to another HMA plant about 45 km (28 miles) north and produce the virgin HMA there. When HIR work began in late April, there were numerous mechanical/electrical problems with the HIR equipment. Altogether these problem delayed any significant work until June 2, 1998. From that time forward there was steady progress. The HIR work was substantially completed on

July 28, 1998. Average daily production for the project is 3625 m^2 (4335 yd^2) through July 21, 1998.

As the project progressed there were adjustments made in the binder content of the virgin HMA and the rejuvenator rate. These changes were made on the basis of SGC compacted specimens of recycled mixture taken from the roadway. The binder content in the virgin HMA was lowered from 3% to 2% during the first week of the project and it remained at 2% for almost the entire project. The rejuvenator rate was lowered from 0.6L/m^2 (0.13 gallon/yd^2) to 0.5L/m^2 (0.11 gallon/yd^2) early in the project and remained at 0.5L/m^2 (0.11 gallon/yd^2) for the rest of the project.

MIXTURE DESIGN AND ANALYSIS OF ROADWAY COMPACTION

Gradation and binder content of the existing mix were determined and testing was done to select an appropriate rejuvenator and rejuvenator content. A soft asphalt cement (AC-5) and two grades of rejuvenator oil were evaluated. The evaluation consisted of DSR testing at 64°C (147°F) and 70°C (158°F) for various blends of rejuvenator and recovered binder from the existing HMA. Figure 1 gives plots of viscosity versus percent rejuvenator for the rejuvenator oil selected for this project.

Several trial blends of virgin HMA with the reclaimed asphalt pavement (RAP) were made in the laboratory using the Superpave gyratory compactor (SGC) for compaction. The SGC revolutions for the traffic loading on the project site are 109. The RAP/virgin HMA ratio was held constant at 80/20 while the variables in these trial blends were rejuvenator content in the RAP and binder content in the virgin HMA. The aggregate for the virgin HMA consisted of minus 19 mm (0.75 inch) crushed gravel with 1% hydrated lime.

Rejuvenator content in the RAP was varied from 0 to 1.3 L/m^2 (0.29 gallon/yd^2) and binder content in the virgin HMA was varied from 0 to 5.3%. The rejuvenator rate as used herein is defined as the amount of rejuvenator applied to an area of one square meter of pavement recycled to a depth of 50 mm (2 inches). It was established that a minimum of 3% binder in the virgin HMA was needed to insure adequate coating in the recycled mixture in the laboratory environment. Holding the binder content in the virgin HMA at a constant 3%, the rejuvenator rate was varied. A rejuvenator rate of 0.6L/m^2 (0.13 gallon/yd^2) resulted in approximately 4% air voids in the recycled mixture at the design compactive effort of 109 revolutions in the SGC. This 0.6L/m^2 (0.13 gallon/yd^2) rejuvenator rate equates to 19% by weight of the binder in the RAP, which is within the range shown in Figure 1 between a PG64-22 and PG70-22. Figure 2 gives the gradation of the recycled mixture.

As a further test on the rutting resistance of the mixture, HIR specimens were prepared in the laboratory with 3% binder in the virgin HMA and 0.6L/m^2 (0.13 gallon/yd^2) rejuvenator in the RAP. These specimens were compacted in the SGC to 7% $\pm$ 1% air voids and then tested in the APA, a commercial version of the Georgia loaded wheel tester. The APA testing was all done in the dry condition. The APA has spaces for testing 6 specimens at a time, and, for comparison purposes, different control specimens were tested along with the HIR specimens. The control specimens were all virgin HMA meeting the MDOT Superpave 12.5 mm (0.5 inch) mixture gradation with different binders including a PG64-22 and several modified binders that met either a PG76-22 or PG70-22. Figure 3 shows the results of the APA testing for 7500 cycles. Rut depth values below 5 mm (0.2 inch) are considered acceptable for the traffic loading on the project location. The HIR specimens compared favorably with the modified HMA mixtures.

Figure 4 gives plots of air voids in the recycled roadway and in SGC compacted specimens of loose recycled mixture collected from the roadway. The roadway air voids are the average of 5 measurements (either cores or correlated nuclear gauge) while the SGC values are the average of three sets of three specimens each. The SGC specimens were all compacted to 109 revolutions.

The data in Figure 4 illustrates the objective of using the SGC to monitor and make adjustments in the recycled mixture. For normal HMA production and in HMA mixture design, the MDOT compaction criterion is 4% air voids at N_{design}. A recycled mixture containing 80% RAP is anticipated to be more harsh than a virgin HMA or an HMA with relatively small amounts of RAP. The air void criterion at N_{design} was, therefore, adjusted downward to reflect this. While no definitive air void level was established at which rutting would be objectionable, a trigger minimum value for SGC air void content of 3% was used. Whenever the SGC air voids for the recycled mixture from the roadway dropped much below 3%, an adjustment in the rejuvenator rate was made to attain an air void level closer to 3%.

Limited data is available on properties of the recovered binder from the recycled mixture. Dynamic shear rheometer (DSR) data ($G^*/\sin\delta$) at 64°C (147°F) is available for the 17,600 m^2 21,050 yd^2) of recycled pavement done in December 1997. Viscosities range from 1.00 kPa (0.15 lbf/in^2) to 8.69 kPa (1.26 lbf/in^2) with an average of 4.67 kPa (0.68 lbf/in^2).

COST DATA

As mentioned above, three pay items were added to the existing contract to cover the HIR work. Prices for these items were negotiated between the contractor and MDOT. Unit prices for these items are expressed below in metric units that have been converted from the English units in the contract:

- Hot in-place recycling $5.2625/$m^2$ ($4.40/$yd^2$)
- Rejuvenating Agent $0.515/L ($1.95/gallon)
- Virgin HMA $41.89/metric ton ($38/ton)

Using these rates, the net cost for the HIR work is $6.55/m^2 ($5.48/yd^2). By way of comparison, the net cost for cold milling 50 mm (2 inches) and replacing with HMA to the grades and cross slopes used for the HIR work, at the prevailing prices for cold milling and HMA in Mississippi, would be approximately 12% less than this cost for HIR. It is thought that the cost of such a HIR process as used on this project will, in a conventional bidding situation, be competitive with other HIR methods. Additional evaluations will be needed to help establish the relative life cycle costs of HIR compared to conventional cold milling and replacing with HMA.

CONSTRUCTION PROBLEMS

There were numerous problems during construction and they fall generally into these categories, in no particular order:

- Roadway conditions not the fault of the HMA contractor or HIR subcontractor;
- Areas where insufficient heating of the existing pavement resulted in inability to get adequate roadway density; and
- Time periods during construction where the HMA contractor provided inadequate compaction equipment.

As mentioned earlier, this roadway was previously recycled by HIR in 1991-1992. All the project planning for the HIR work described herein, including the recycled mixture design, made the assumption that the roadway cross slope was a uniform 1.5% as was standard when the last rehabilitation was performed in 1992. In actuality, the cross slope was not nearly as uniform as assumed. In areas where the cross slope was not the anticipated 1.5%, the quantity of recycled mixture was either too much or not enough to meet the grade criteria of matching the paved shoulder grade and maintaining a cross slope of 2% in the finish roadway. For interstate highways such as this, correct cross slope is important and the objective was to maintain the cross slope as close to 2% as possible. When the existing cross slope was greater than 1.5%, it was necessary to make slight upward adjustments in the paver screed to gradually raise the grade of the roadway to use the excess recycled mixture, as there was no feasible way to waste the excess material. If the screed adjustment was not made in time, the paver hopper would overflow with recycled mixture which would result in the pugmill mixer on the HIR paving train clogging with recycled mixture and causing a shut down of the operation to dispose of the extra material. When the existing cross slope was less than 1.5%, the only way to address the resulting shortage of recycled material was to reduce the cross slope and/or increase the amount of virgin HMA going into the recycled mixture. If the adjustments were not made soon enough, the paver would run out of material causing a shutdown of the operation. Both of the scenarios described above would result in some portion of the recycled pavement to cool to a point where it was impossible to get adequate density and in many cases also produced poor ride quality in that area. Variations in the amount of virgin HMA also changed the mixture composition from the 80/20 job mix formula.

With practice and close attention, some of the areas with cross slope deviations could be handled without shutting down the operation. Even so, this is judged to be an unforeseen condition that should not detract from the appeal of HIR. Such non-uniform cross slope would probably only be found in Mississippi on previous HIR projects where there was insufficient attention given to producing a uniform cross slope.

One of the objectives in the recycled mixture design philosophy used for this project was to get as much rejuvenator into the existing HMA as possible. For this reason, a decision was made to use as little binder as possible in the virgin HMA. This approach worked well as long as there is sufficient heat to soften the binder in the existing HMA to give a binder viscosity that facilitates good coating of the entire recycled mixture. It was observed that, when the temperature of the recycled mixture in the paver hopper fell below 130°C (265°F), a minor amount of poorly coated particles was present. For this reason the contractor was encouraged to maintain this temperature level for recycled mixture deposited in the paver hopper.

Another problem related to insufficient heating of the recycled mixture was the difficulty or impossibility to get the required density. The HIR subcontractor had difficulty in consistently maintaining adequate temperature in the recycled mixture. At least part of this was probably due to mechanical/electrical problems with the HIR equipment. The MARTEC equipment had never before been used in climates as hot and humid as Mississippi and some equipment modifications were made during the project to adjust to this. Also related to this were occasional areas where moisture that infiltrated through the numerous cracks in the pavement was trapped in the pavement structure and this resulted in heat losses.

Another source of density problems is thought to be insufficient compaction equipment provided by the HMA contractor during some portions of the project. There were periods when insufficient sizes or numbers of rollers were present to attain adequate roadway density.

It is reasonable to infer that the unusual relationship where the HMA contractor provided the virgin HMA, paver and compaction equipment and operators while the HIR subcontractor provided the HIR equipment and operators presented some unusual conditions. The failure to have one entity in total control of the entire operation did result in inefficiencies and miscommunication.

A total of 10% of the project area will need corrective action due to either inadequate density or excessive roughness (almost exclusively small bumps and poor construction joints). Of this 10%, approximately 9% falls into the low-density category and 1% into the roughness category. It is impossible to determine how much of these areas needing corrective action can be attributed to the different problem categories. What is important is that all of the problems can be easily addressed in subsequent HIR projects. All the problems encountered on this project are operational in nature and do not indicate any inherent problem with the MARTEC HIR equipment.

CONCLUSIONS

This paper describes the first use of the MARTEC HIR equipment in the United States. While construction problems were encountered, it has been shown this equipment can adequately heat an existing HMA pavement to permit hot in-place recycling to a depth of 50 mm (2 inches). Subsequent projects need to insure there is one entity in control of the entire operation. Both acceptable density and ride quality are attainable.

This project demonstrated a method of designing the HIR mixture and monitoring construction with Superpave technology. Preliminary DSR testing was used to select a rejuvenator and establish a beginning point for laboratory design. The recycled mixture design was done using the same Superpave compaction parameters MDOT uses for virgin HMA mixture. Quality control testing with a SGC at the field laboratory was used to make adjustments in the rejuvenator rate and binder content in the virgin HMA. Preliminary DSR data for recovered binder from the recycled mixture indicates acceptable properties. Since there is as yet no Superpave strength test, the APA was used to compare the HIR mixture with a virgin HMA mixture containing differing binder grades and the results indicated satisfactory resistance to rutting.

ACKNOWLEDGMENT

Acknowledgment is made to the Federal Highway Administration and the HMA contractor, Dickerson & Bowen, for their participation in the mixture design phase of this project. Their efforts made it possible to complete a complex mix design in a short period of time. The Federal Highway Administration is also acknowledged for their encouragement to pursue this project and approval of the contracting arrangements.

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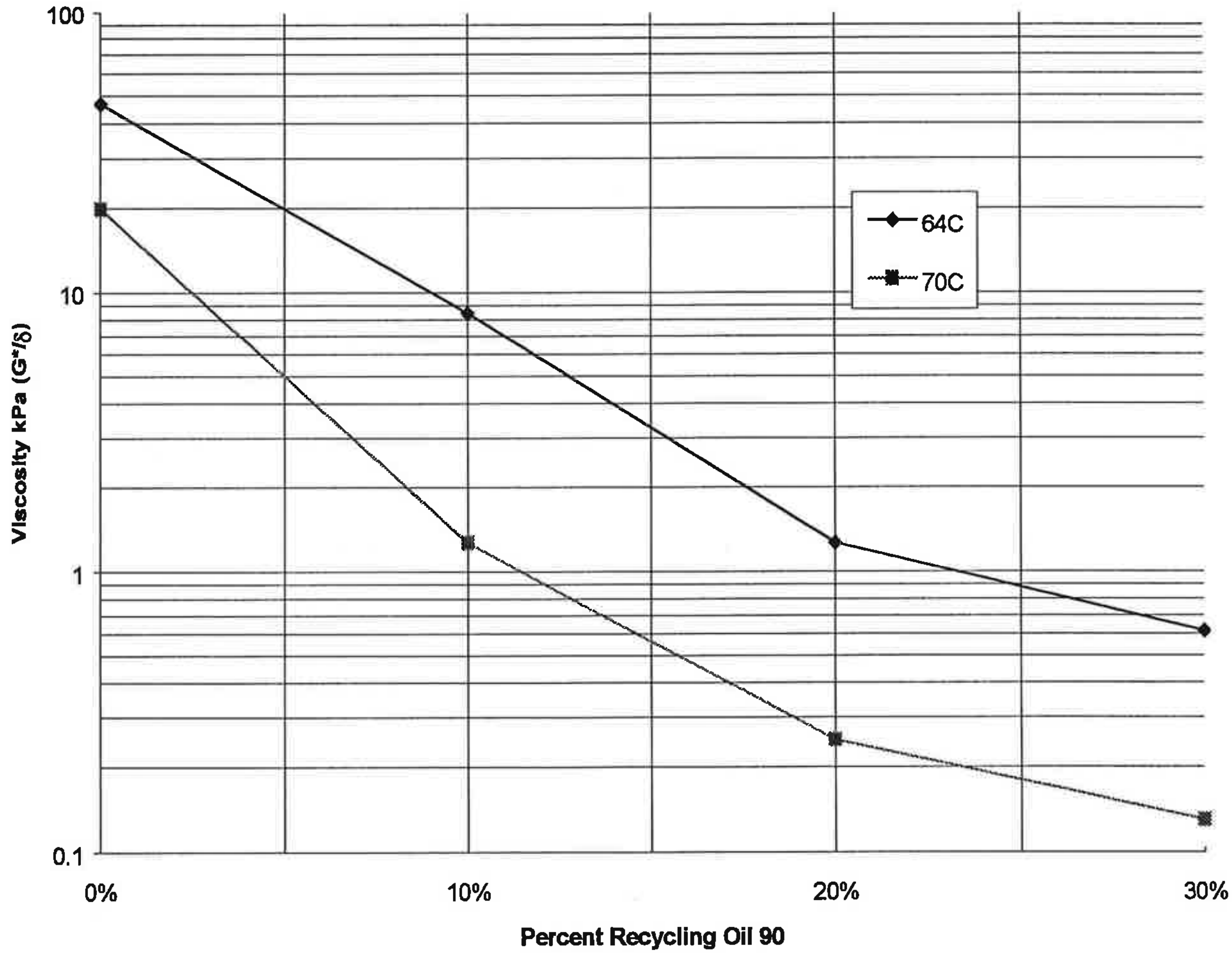

Figure 1. Viscosity for Blends of Recovered Binder + Recycling Oil 90
1 kPa = 0.15 lbf/in^2

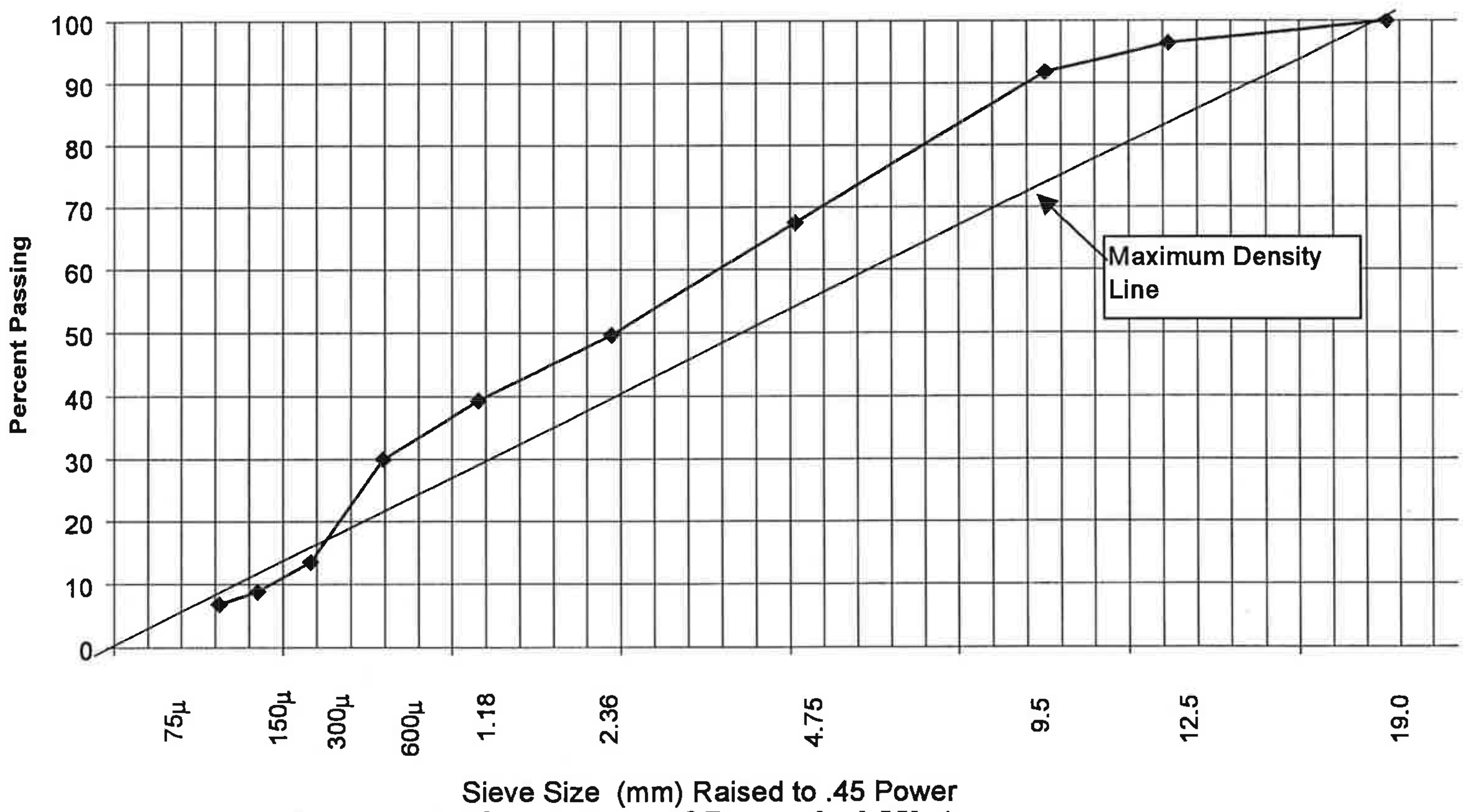

Figure 2. Gradation of Recycled Mixture
25.4 mm = 1 inch

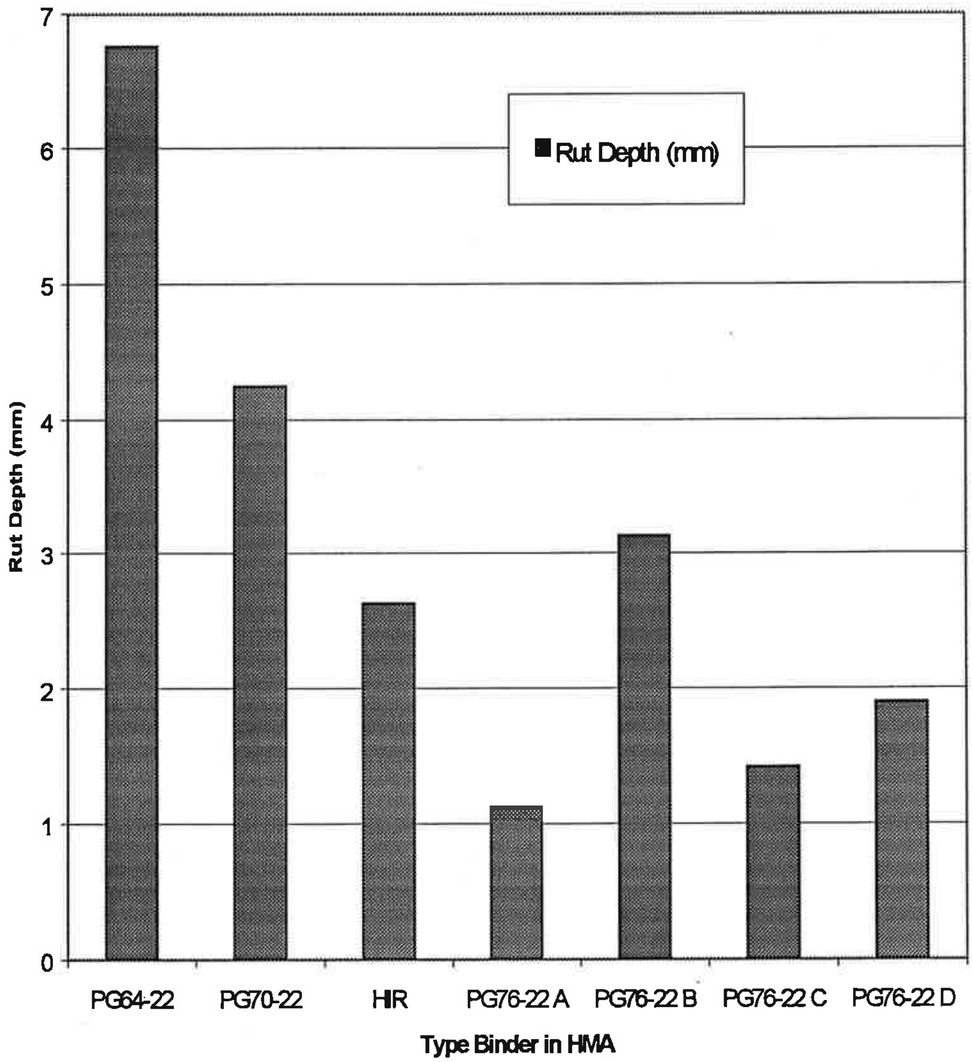

Figure 3. Asphalt Pavement Analyzer Rut Depths at 7500 Cycles and 49° C
25.4 mm = 1 inch

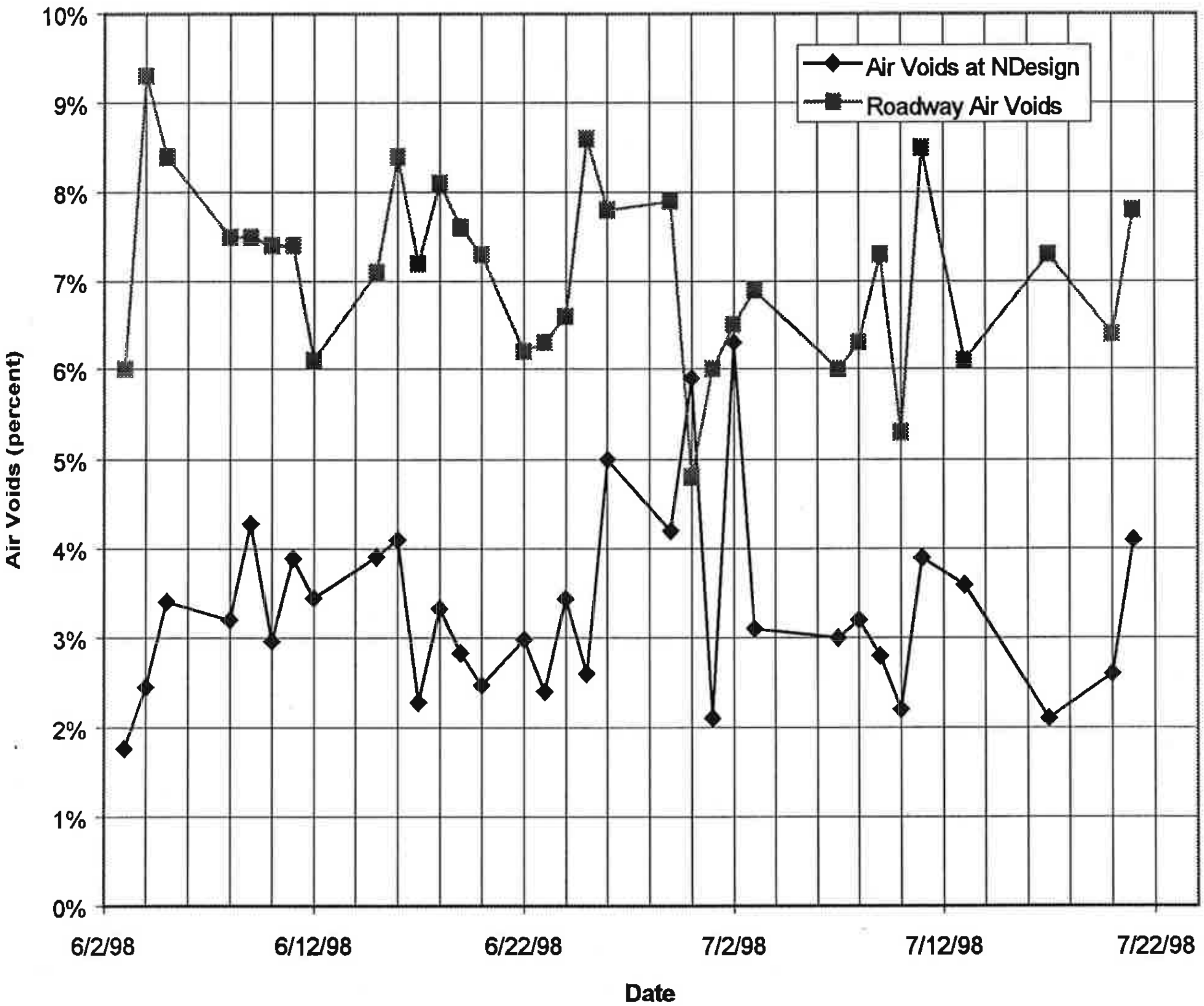

Figure 4. Plots of Air Voids for Roadway Compaction and SGC Compacted Field Specimens

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